A COMPACT 36 kJ ELECTRON BEAM SYSTEM FOR LASER PUMPING*

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Abstract

An electron beam machine consisting of six modules is being constructed for the 'B' amplifier of the RAPIER KrF laser system. Each module consists of a diode, a 5 Ω positive charged water dielectric Blumlein pulse-forming line, and a five stage Marx generator. Separate 25 cm x 41 cm electron beams are formed in magnetically isolated diodes which when arranged in groups of three produce two nearly continuous 25 cm x 125 cm beams that enter the laser cell from opposite sides. The pulse-forming lines operate at 450 keV and produce 150 ns long pulses. The lines employ electrically triggered annular SF_6 output switches. The two concentric transmission lines of each pulse-forming line are charged in 1 μs through symmetric circuits to reduce diode prepulse voltage. The six modules together with the laser cell will occupy less than 15 m^2 of floor space.

System Description

The RAPIER 'B' amplifier is intended not only to deliver 500 J of KrF laser output but also to demonstrate the development of a compact, modular, pulsed power and electron beam system that would permit the construction of even larger KrF amplifiers. The width of individual modules has been minimized so that modules can be arrayed side-by-side to produce a nearly continuous electron beam of arbitrary width. Only minor design changes would be required to permit vertical stacking of modules as well.

An artist's conception of the 'B' amplifier system is shown in Fig. 1.

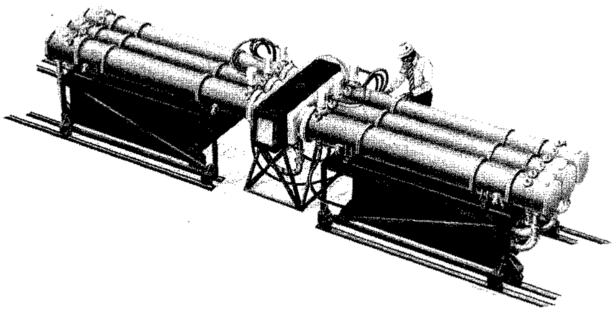

Fig. 1. RAPIER 'B' amplifier

Two sets of three modules are located on each side of a 30 cm wide x 40 cm high x 125 cm long laser cell which will be filled with a mixture of noble gases and fluorine at a pressure of 2 atm. Each pulsed power module consists of a Marx generator located in an oil-filled tank beneath a cylindrical 5 Ω water dielectric pulse-forming line. At the rear of each line is an oil-filled chamber which contains all of the charging connections as well as connections to the adjacent triggered output switch. At the front of each line adjacent to the laser cell is an evacuated chamber which contains the magnetically isolated diodes, individual diode insulators, and cathodes which produce 25 cm high x 41 cm wide electron beams. The kinetic energy of the beam electrons is 450 keV and the current produced by each module is 90 kA. Thus each beam delivers 6 kJ of energy in a 150 ns pulse for a total energy of 36 kJ. Each module is 42 cm wide. The entire machine as pictured is 8.2 m long, 1.85 m wide, and 1.45 m high and thus occupies 15 m^2 of floor space.

The sections which follow describe the essential design features of the 'B' amplifier, its operating parameters, and the present status of the project.

Marx Generator

Each of the six Marx generators is oil insulated and contains five stages. Each stage is composed of two 0.3 μfd, 100 kV capacitors connected in parallel and an air insulated 100 kV midplane triggered spark gap. The capacitors are charged through 2 kΩ $CuSO_4$ resistors and the switch midplanes are coupled by 300Ω strings of 2 w composition resistors as shown in Fig. 2. The Marx generator stores 15 kJ of energy when charged to 100 kV though it will normally be operated at 75 kV. The inductance of the Marx itself is approximately 1 μh. Each generator fits within the 42 cm width associated with each module and occupies a volume of 0.7 m^3.

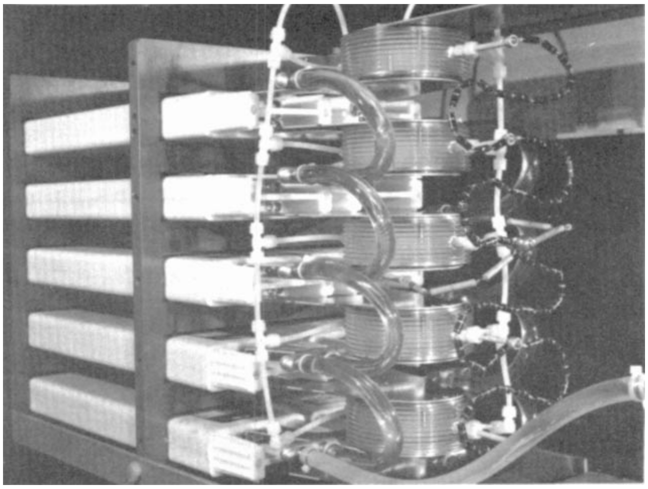

Fig. 2. 'B' amplifier Marx generator

Charging Circuit

The two transmission lines of the Blumlein pulse-forming lines are charged from the Marx through a symmetric or balanced circuit as shown in Fig. 3 in order to minimize the voltage which appears across diode during charging. As a consequence of this circuit, both terminals of the Marx generator must be isolated from ground and connections must be made from the Marx to all three pulse-forming line conductors.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 1981	**N/A**	**-**

4. TITLE AND SUBTITLE
A Compact 36 Kj Electron Beam System For Laser Pumping

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lawrence Livermore National Laboratory P. 0. Box 5508 - Livermore, CA 94550

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

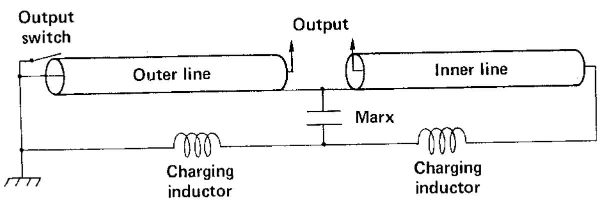

Fig. 3. Charging circuit

A 4.5 µh inductor is connected between the negative terminal of the Marx and ground to form half of the charging circuit. The other half consists of two separate inductors, one of 1.5 µh located in the oil-filled chamber at the rear of the pulse-forming line and one of 3 µh located inside of the innermost conductor of the pulse-forming line as shown in Fig. 4. The connection between the two inductors is made with a short section of high voltage cable which runs inside a tube that connects the intermediate conductor of the pulse-forming line to the positive terminal of the Marx generator.

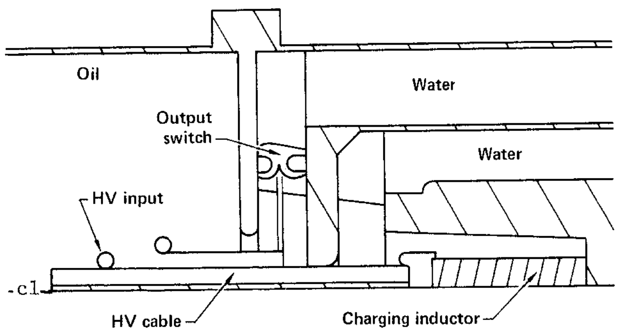

Fig. 4 Output switch configuration

This arrangement permits all charging connections to be made through the end of the pulse-forming line so that lines could be stacked vertically as well as horizontally. The total circuit inductance including that of the Marx and all connections is approximately 3.5 µh and results in a 1.2 µs charging time for the line.

Pulse-Forming Line

The Blumlein pulse-forming line is made of aluminum, uses water as a dielectric medium, has a 5 impedance and is 38 cm in diameter. The triaxial section is 2.5 m long resulting in a 150 ns output pulse. It's only unique feature is the use of a plastic disc to control the electric fields at the end of the intermediate conductor of the line as shown in Fig. 5. The fields at the surface of the intermediate conductor are kept below 100 kV/cm when the line is charged to 450 kV. The fields within the plastic reach 600 kV/cm but are well below its breakdown strength.

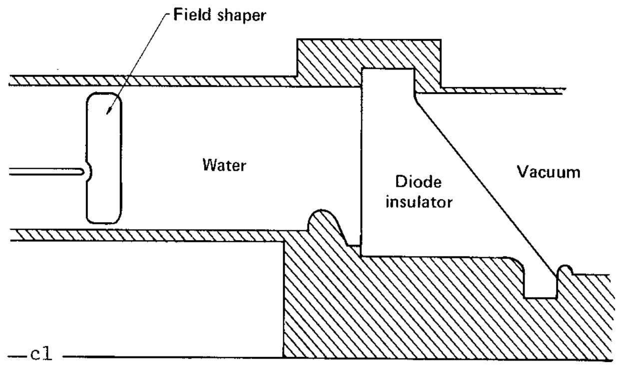

Fig. 5. Diode configuration

Output Switch

The output switch is an annular, SF_6 insulated, midplane triggered spark gap shown in Fig. 4. It operates at 150 psig with a 1 cm gap. The annular design yields multichannel operation for low inductance, distributes spark damage, and permits use of the charging arrangement described above. The electrodes are made of a copper-tungsten composite material to minimize erosion. At 450 kV the output switch passes 27 mC and produces a 20 ns rise time pulse.

Diode

The diodes for the 'B' amplifier system are housed in two separate chambers. Each chamber contains three magnetically isolated electron beam diodes sharing a common vacuum system. The individual diode insulators have a conical shape as shown in Fig. 5. This shape preserves optimum field angles and results in a higher voltage stand-off for a given diameter than a flat insulator but at the expense of a higher inductance and more complex fabrication. Due to the combination of diode inductance, cathode turn-on, and plasma closure, a peak voltage of nearly 600 kV will be generated across the insulator for an output pulse which averages 450 kV.

Electron Beams

The electron beams are composed of electrons emitted from plasmas which form when a surface is subjected to a high electric field in vacuum. Because of the relatively modest applied field of 180 kV/cm (a 2.5 cm anode-cathode separation) some field enhancement is required to obtain a uniform and consistent plasma. This is accomplished by constructing the cathode from a stabbed 0.25 mm thick stainless steel sheet.

The combination of applied electric fields and self-magnetic fields in the diode result in a "pincushion" distortion of the electron beam shape during acceleration in the diode. This distortion is corrected by shaping the cathode as shown in Fig. 6. The beam size at the anode is about 25 cm x 41 cm at an average space charge limited current density of 90 A/cm^2.

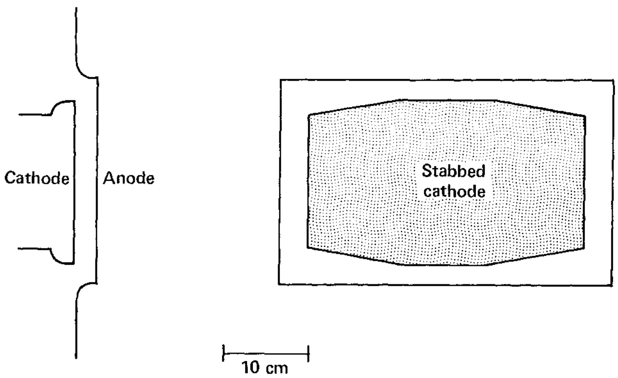

Fig 6 'B' amplifier cathode

The evacuated diode will be separated from the pressurized laser cell by a 25 μm thick Inconel foil supported by a slotted plate of maraging steel. The diode side of this plate will be covered with a 10 μm thick titanium foil in order to keep the electric fields uniform in the diode and thus maximize the transmission of this structure.

System Triggering

The three output switches of the pulse-forming lines on each side of the laser cell will be triggered from a single electrical pulse. This pulse will be generated by a spark gap located at the rear of one of the lines and will be distributed to adjacent lines through short oil-filled transmission lines. The trigger gap (currently in use on a single line) is charged from the Marx generators to approximately 2/3 of the line charge voltage. The trigger gap will, itself, be triggered by a laser pulse generated elsewhere in the RAPIER system. The gap contains an R-C biased midplane electrode whose function is to insure that a trigger pulse is generated even if the Marx generators should prefire at a lower than desired voltage or if the laser triggering pulse should not appear.

The three Marx generators on each side of the laser cell will be resistively coupled to a single trigger signal generated externally. This coupling insures that all three Marx generators will fire if one of them prefires.

Status

The output switch, the balanced charging hardware, the intermediate conductor field-shaping disc, and the output switch triggering circuit have been tested extensively at 525 kV on a 60 ns pulse-forming line coupled to a resistive load. Two coupled full scale Marx generators have also been tested extensively at 100 kV charge voltage. The generation of the desired electron beams has been studied on a machine with output characteristics similar to a 'B' amplifier module. A beam of the proper size, current, voltage, and pulse length has been obtained and transmission of the foil support structure has been measured to be $\gtrsim$70%.

A complete, full-scale prototype of one of the 'B' amplifier modules has been assembled with a diode load and separately with a resistive load. The prototype is shown in Fig. 7 early in its assembly with a resistive load. It has been tested to line charge voltages of 525 kV into both resistive and diode loads.

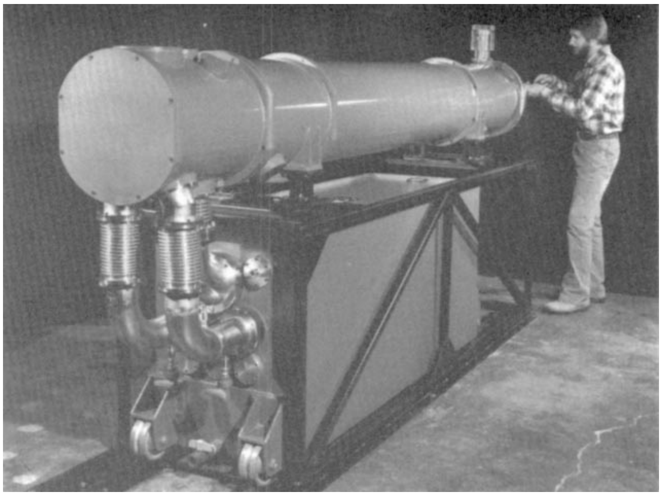

Fig. 7 Prototype module

Output pulses for both cases are shown in Figs. 8 and 9. With the cathode geometry described above > 7.5 kJ has been delivered to a calorimeter at the anode plane. Testing has not been extensive (<300 shots total), the machine has not yet been characterized at its designed operating point of 450 kV and 6 kJ output, and electron beam properties other than total energy delivered have not been determined.

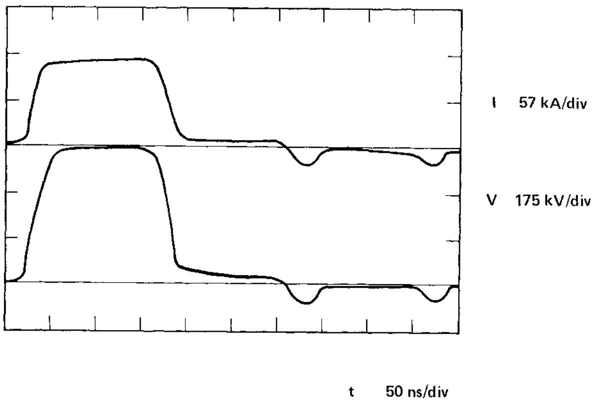

Fig. 8 Output pulse - resistive load

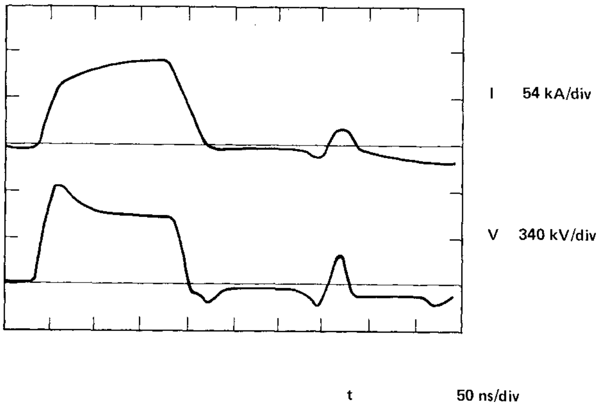

Fig. 9 Output pulse - diode load

More than 75% of the hardware needed to construct the full 'B' amplifier electron beam system is in hand. More than 95% will be delivered by mid-July. Installation of Marx tanks, support frames, and auxiliary systems for the 'B' amplifier is underway and the assembly of the second module is in progress.

Summary

A compact, modular 36 kJ electron beam system for the RAPIER 'B' amplifier has been designed and is currently under construction. Component development has been completed and a prototype module has been assembled. This module has been operated at voltages 15% above the design goal. Further testing and characterization of the module is in progress.

Acknowledgments

The author is deeply indebted to T. M. Petach, J. C. Swingle, D. A. Masquelier, S. B. Brown, W. G. Smiley, and D. S. Biggert without whose expertise and assistance this work would not be possible.

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*Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.